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Quality and Quantity of Leachate from Raw Mined Colorado Oil Shale

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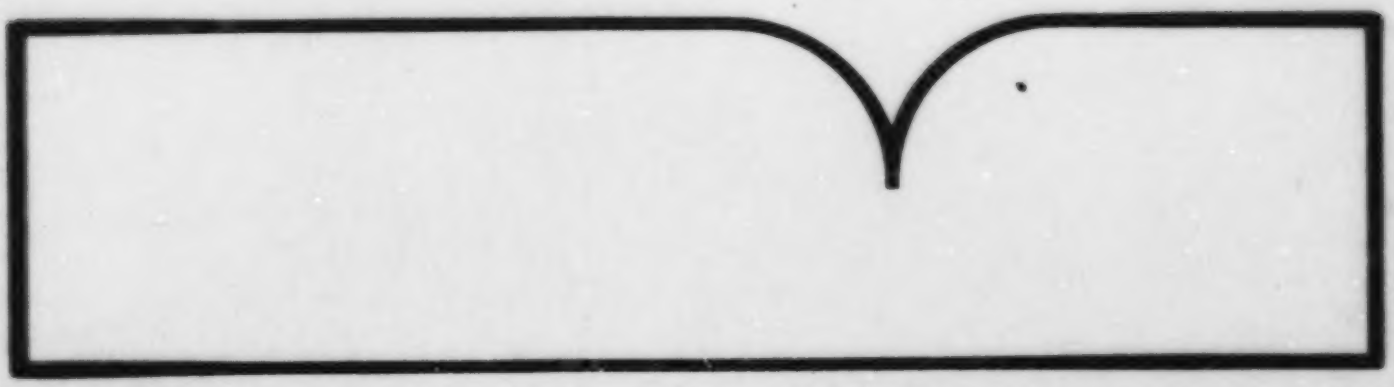

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16. ABSTRACT

This paper discusses and EPA sponsored study to asses the potential environmental impacts of leachates from raw mined western oil shales. The study was undertaken as a cooperative effort of the Environmental Protection Agency, Colorado State University, Rio Blanco Oil Shale Company, Cathedral Bluffs Shale Oil Company, and the Oil Shale Projects Office of the Bureau of Land Management. This paper presents the results of three years evaluation of the quantity and chemical characterization of leachates generated from onsite field collectors along with laboratory shake tests on raw mined oil shales from the C-a and C-b Federal lease tracts in western Colorado. The findings are indicators of the levels of common and trace species that can be expected to occur in field generated raw shale leachates.

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ENVIRONMENTAL RESEARCH BRIEF

Quality and Quantity of Leachate from Raw Mined Colorado Oil Shale

David B. McWhorter

Introduction

Commercial utilization of the vast energy resource represented by the oil shale deposits in Colorado, Wyoming, and Utah is more nearly a reality now than ever before. Raw mined shale piled on the ground surface constitutes a relatively permeable mass of particles ranging in size from silt and clay to boulders that readily accommodate infiltration of incident precipitation. A portion of the waters that infiltrate the piles is evaporated and a portion percolates downward and eventually becomes seepage from the pile.

Fragmentation of raw shale and placement in a different hydrogeochemical environment creates the potential for the release of undesirable chemicals into waters contacting the materials. A previous laboratory study suggested that the potential was sufficient to warrant a field data collection program. A cooperative field study was initiated on April 1, 1980, under EPA Cooperative Agreement CR807513. The major objective of the research was to determine the quantity and quality of leachate generated in storage piles of raw mined oil shale by establishing subsurface collector systems at various depths beneath the surface in order to intercept percolate through the piles. A secondary objective was to compare the data from the field with that generated from laboratory columns to assist in the assessment of leaching columns as a useful test of potential chemical release.

The research was originally conceived as a cooperative project among Colorado State University (CSU), U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS) Area Oil Shale Office (now the BLM Oil Shale Project Office) and the Rio Blanco Oil Shale Company. The first leachate collection systems were installed on Federal lease tract C-a under that agreement and the first leachate sample was collected in August 1980. Subsequently, the scope of work was broadened to include a similar installation on Federal lease tract C-b in cooperation with the Cathedral Bluffs Shale Oil Company. The leachate collection systems at C-b were constructed during the fall, 1980. The results reported herein were obtained during the 1981-1983 study period.

Construction of Collection Systems

That seepage of percolate through the raw shale piles at C-a and C-b lease tracts occurs at less than full saturation is dictated by the fact that the rate of supply from precipitation is intermittent and nominally less than the saturated hydraulic conductivity of the materials. The pressure of the percolating solution is less than atmospheric under such circumstances. Even though methods for measuring and sampling seepage at negative gage pressures are available, the decision was made to utilize an impervious surface buried in the pile as a collection mechanism. The rationale included the fact that the materials are quite coarse and, therefore, little change in the flow pattern would be induced by artifically creating a perched water table on the impervious surface of the collector.

Materials and Methods

The collection system installed at C-a includes three collectors buried beneath raw shale at depths of 5, 10, and 15 feet beneath the surface of the shale. Each collector consists of a 10 foot by 10 foot square (93,000 cm^2) of impervious material, contoured so that the intercepted percolation is conducted to a drain pipe located near the center of the collector (Figure 1). In construction of the collectors, the first step was preparation of a sand bed upon which a continuous sheet of polyethylene was placed. The foundation, upon which the sand bed was prepared, is natural ground that was graded to form small pads for the collectors. A hole of appropriate size was cut in the polyethylene through which the outer drain pipe can be raised through the sheet from the bottom. The outer drain pipe was 1½-inch diameter PVC and served the dual

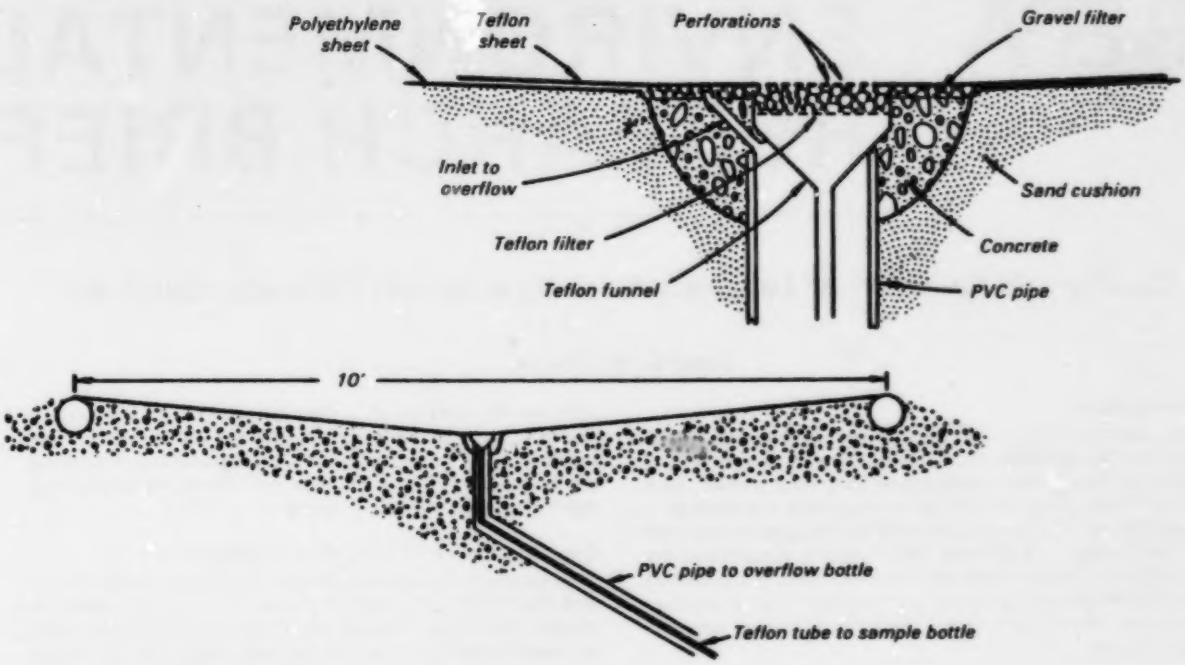

Figure 1. Construction details of the buried collectors—C-a tract.

functions of conductor pipe for the inner drain tube and as a drain pipe for any percolate that was collected on the polyethylene sheet.

Inside the outer drain pipe, a teflon tubing was placed. The inner drain tube was connected to a teflon funnel that projected upward through the polyethylene sheet. Concrete was placed around the PVC pipe and supported the teflon funnel as shown in Figure 1. A teflon screen (filter) was situated in the funnel. The next step was to place a thin layer of gravel-size material over the top of the concrete and funnel. The screen in the funnel prevents the gravel from entering the teflon tubing.

The entire 10 foot by 10 foot area was covered with a teflon sheet. It was not possible to obtain a single teflon sheet of the size required, so it was necessary to overlap several strips that were cut approximately 11 feet long. The width of each strip was about 30 inches. The overlap was of a shingle type so that leakage through the teflon was minimized. Directly above the teflon filter, holes were drilled through the teflon sheet so that percolate collected on the teflon sheet would pass directly into the funnel and then into the inner drain tube. As shown in Figure 1, a hole was formed in the concrete. The purpose of this hole was to provide for flow of any percolate collected between the teflon and polyethylene sheets to the outer drain pipe.

The function of each collector, constructed as described above, is visualized as follows. Percolate through the overlying raw shale will first encounter the teflon sheet. Most of the intercepted percolate passes over the teflon sheet and into the funnel and inner drain tube. In the event that a portion of the percolate makes its way through the teflon via the overlapping joints or punctures, it is collected on the underlying polyethylene sheet and conducted to the outer drain pipe. In this way, any percolate issuing from the inner tube will have contacted only teflon. The total percolate from both the inner and outer drains is indicative of the quantity of percolate intercepted.

The inner and outer drain tubes conduct the percolate by gravity from the collectors to sample bottles located in a small shelter at the toe of the shale pile. The teflon inner lines are connected to teflon sample bottles as shown in Figure 2. The sample bottles designated A, B, and C are 2 liter bottles with teflon connections. Figure 3 shows the details of the connections to the bottles and of the teflon block in which the resistance/temperature probe is fixed. Note that the connections to each sample bottle are designed so that bottle A must fill before percolate is transported to bottle B. Bottle B is the second bottle to fill and so on. Percolate in excess of six liters is collected in the large overflow bottle (D). Bottles D and E are both polyethylene containers of approximately 40 liter capacity.

The collectors established at the C-b lease tract are a very similar construction. At the C-b site efforts were made to turn up the edges of the teflon and polyethylene sheets to form a somewhat deeper collector than those established at the C-a site. The purpose was to minimize any tendency for flow to be diverted around the collectors by the somewhat greater piezometric head in the water directly above the collector surface as compared to that exterior to the

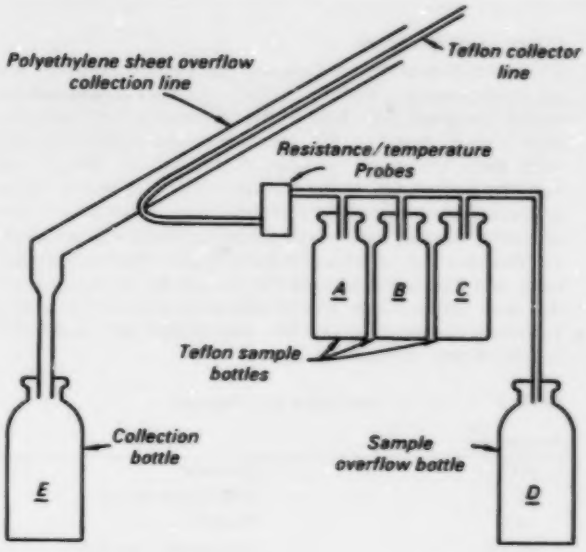

Figure 2. Schematic of the collection bottle arrangement.

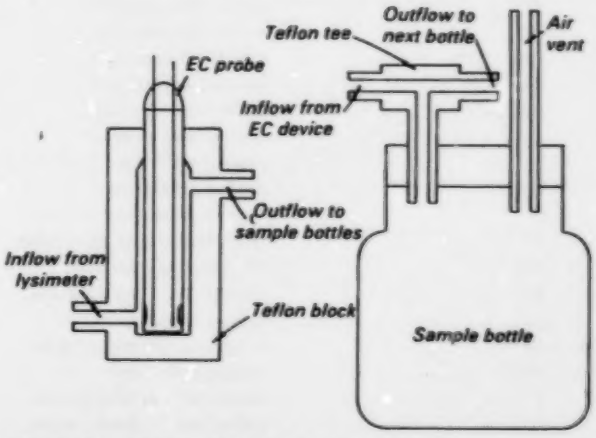

Figure 3. Details of the electrical conductivity.

collector but at the same elevation. The only other significant difference is the depth of burial. At the C-b site, the collectors are buried to depths of 10, 15, and 20 feet. The corresponding depths at C-a are 5, 10, and 15 feet. At the time of construction, the collectors were located on the edge of existing shale storage piles. Subsequent growth of the piles has made the collectors integral parts of piles and no artificial boundary effects are present to our knowledge.

Placement of Raw Shale

The raw shale placed over the collectors at C-a was extracted from the R-5 zone near the base of the first retort (retort "zero"). The material mucked from blasts 1, 2, and 3 on May 8, 16, and 30 with roof elevations of 6106 feet (48 feet below top of R-5), 6121 feet (33 feet below top of R-5), and 6141 feet (13 feet below top of R-5) was placed in three piles on the surface from which shale was taken for placement in the period May 18-22. The material directly in contact with the teflon sheets was hand placed to minimize the probability of puncture. After this hand-placed layer was completed, some 10-12 inches of material were shoveled on to the collectors by hand. Subsequent lifts were placed with a front-end loader. During this period, alternate loads were taken from blast 1 and blast 2 piles so that the bottom two-thirds of the shale over the collectors is a mixture of muck from blasts 1 and 2. Approximately the upper third of the shale over the collectors came from the muck pile from blast 3 and was placed in the periods of June 9-11 and June 17-18.

The raw shale at C-b was placed on the collectors during the period of December 8-10, 1980. Material mucked from the intermediate void level of the ventilation-escape shaft and the service shaft was utilized. The material from the V-E shaft came from an interval between elevations 5245 and 5265 feet. The extraction interval from the service shaft was 5340-5360 feet. Both intervals are in the "B" Groove, an interval of lean oil shale at the base of the rich Mahogany zone. The materials were placed on the collectors in the same manner as utilized at C-a. It is estimated that the final mixture of materials over the collectors is 40% from the V-E shaft and 60% from the service shaft.

Data Collection and Analysis Procedures

Precipitation

Precipitation is measured at both field installations with recording rain gages. The recording rain gage at C-a is located approximately 150 feet north of the collectors at a site where it is undisturbed by other operations at the site. A recording gage is installed immediately adjacent to the 10-foot collector at the C-b installation. Tract personnel collect the charts, and service and maintain these gages. Copies of the charts are sent to Colorado State University. Any differences in precipitation as interpreted by tract and CSU personnel are reconciled and a final record of cumulative precipitation at both sites is prepared. No chemcial analysis of incident precipitation has been made. Insofar as the chemistry of both the precipitation and shale are site-specific, so also is the quality of the leachate.

Leachate Volume

All leachate collected on the teflon or polyethylene sheets is routed to collection vessels through drain lines as previously described. Generation of leachate is sporadic in response to random precipitation and snow melt. No attmept was made to measure instantaneous seepage rates. Rather, a record of cumulative volume of leachate for each collector is prepared. Members of the staffs at Rio Blanco and Cathedral Bluffs monitor the volumes of leachate in all of the collection vessels at the respective sites. From time to time, CSU personnel are on site and make the measurements, but usually the tract personnel forward the volume measurements to CSU for tabulation.

Sampling for chemical analysis is focused on the teflon bottles labeled A, B, and C (Figure 2). These bottles are emptied and volumes recorded on a very frequent basis, while the overflow bottles designated D and E are emptied less frequently. Volumes are recorded only when the

bottles are emptied. This procedure sometimes results in abrupt increases in leachate volume that are related to the vessels being emptied rather than to a flow event. Overall correspondence between precipitation and leachate generation is not masked by this procedure; however, instantaneous flow rates calculated from the record of cumulative leachate volume would be unreliable.

Sampling

Provision was made for a flow-through electrical conductivity probe and thermocouple to be located in the teflon collection line, upstream of the collection bottles. For one period during 1980, a data logger was used to record electrical conductivity (EC) and temperature of the leachate at the C-a facility. Unreliable operation of this equipment forced abandonment of its use, however. Field temperature and EC were measured at the time the bottles were sampled for chemical analysis.

The staffs of Rio Blanco and Cathedral Bluffs monitored the collectors and took the samples as they became available. The samples were chilled and CSU personnel were notified. CSU personnel traveled to the site and returned the samples to the CSU laboratory where they were prepared for analysis. In some instances, the samples were shipped directly to CSU. Each sample was divided into 3 aliquots, one of which remained as raw leachate, one of which was filtered through a 0.45 micron filter, and one of which was filtered and acidified with nitric acid. Normally these procedures are accomplished in the field, but since the samples often remained in the collection bottles in the field for periods up to a few days before sampling occurred, little would be gained by field preparation.

Laboratory Leaching Tests

An objective of this project was to assess laboratory leaching tests relative to their utility as predictors of the quality of waters in field-generated leachates. Samples of the raw shales directly overlying the shallowest collectors at both sites C-a and C-b were brought to the laboratory and subjected to the ASTM extraction test entitled "Proposed Methods for Leaching of Waste Materials." This ASTM test "is intended to determine collectively the immediate surface washing and the time-dependent diffusion-controlled contributions to leaching from the waste." Only the water shake extraction test was performed. A known dry weight of raw shale (700 g in these tests) was placed, together with 2800 cm^3 of distilled water, in a vessel and closed. The vessel was agitated by a modified paint-shaker apparatus that imparted both lateral and vertical reciprocating motion to the vessel. Agitation was continued for 48 hours, after which the solid-liquid mixture was allowed to separate by gravity for about one hour. The solution was decanted into a compressed nitrogen barrel filtering apparatus and filtered through a 0.45-micron filter. The filtered solution was preserved for chemical analysis.

Column leach tests had been performed previously on a few raw shales. These same materials were subjected to the test described above. The results of the water shake extraction are compared with data from the column tests in a subsequent section.

Chemical Analysis

A list of chemical parameters and the method used for their determination is given in Table 1. As part of the quality control program practiced in the laboratory, EPA samples with known and variable concentrations were analyzed with each group of samples. If results for the known samples deviated more than 10 percent from the true value, analyses were repeated until satisfactory agreement was obtained. Samples were occasionally spiked with a known and multiple standard additions were run to check completeness and determine sample matrix effects. Standards are run and instruments are recalibrated with a frequency sufficient to detect and correct instrument drift and other problems that sometimes arise.

Table 1. List of Parameters and Methods

Parameter	Method
pH	Electrode
EC	Wheatstone bridge
ALK	Titration
HCO_3	Calculation from ALK
CO_3	Calculation from ALK
H_2CO_3	Calculation from ALK
TDS	At 180° gravimetric
F	Ion chromatography
Cl	Ion chromatography
PO_4	Ion chromatography
NO_3	Ion chromatography
SO_4	Ion chromatography
Zn	Atomic adsorption
Fe	Atomic adsorption
Co	Atomic adsorption
Li	Atomic adsorption
V	Flameless atomic adsorption
NH_3	Ion selective electrode
B	Inductively coupled plasma
Cd	Atomic adsorption
Be	Inductively coupled plasma
Mg	Atomic adsorption
P	Inductively coupled plasma
Si	Inductively coupled plasma
Mo	Inductively coupled plasma
Mn	Inductively coupled plasma
Ni	Atomic adsorption
Ne	Atomic adsorption
Cu	Atomic adsorption
Al	Inductively coupled plasma
Ca	Atomic adsorption
Ba	Inductively coupled plasma
K	Inductively coupled plasma
Cr	Atomic adsorption
Sr	Inductively coupled plasma
Pb	Atomic adsorption
Ag	Atomic adsorption
Tl	Flameless atomic adsorption
Se	AA (Hydridegeneration)
As	AA (Hydridegeneration)
Hg	Cole vapor cell
Total N	Kjehdahl

Results

Precipitation and Leachate Volume

The volumes of precipitation and leachate generated at both experimental sites were measured. Figure 4 shows the cumulative volume of leachate measured during each year from the collector buried at a depth of 20 feet on the C-b lease tract. Also shown in Figure 4, for comparison, is the cumulative precipitation measured at C-b. The monthly plotting interval masks the fact that the collector system responds to precipitation but with a lag of some 5-10 days. A total of 6.15 cm of leachate was measured in 1981, representing 20 percent of the precipitation measured over the same time period. The C-b, 10-foot and C-b, 15-foot collectors produced 4.36 cm (14 percent) and 6.39 cm (21 percent) of leachate, respectively. The total volume of leachate collected over the study period at C-b ranged from 11.52 cm to 17.02 cm, and represents 12% and 17% of the total precipitation, respectively. Such volumes of percolate are large in the perspective of anticipated natural recharge rates for the area. The relatively large volumes are attributed to the fact that the piles are very pervious and bare of vegetation, both conditions which tend to minimize runoff and evapotranspiration losses that operate on the undisturbed ground.

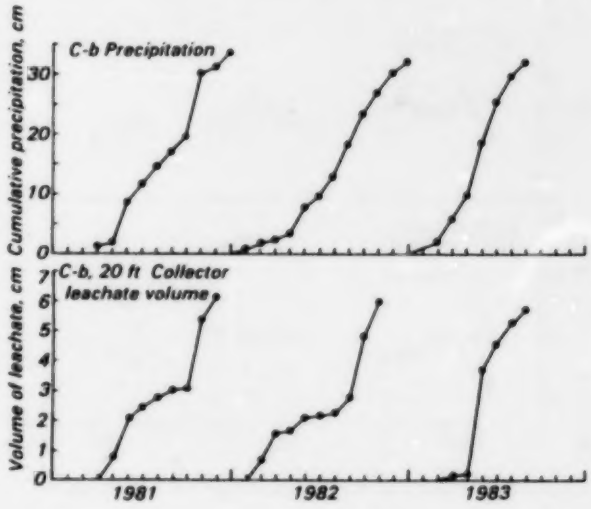

Figure 4. Volumes of leachate and precipitation at C-b.

The close agreement between measured volumes of leachate from the 15-foot and 20-foot collectors on the C-b tract suggest that the volumes measured in these two collectors are the most reliable volume data collected in the study. The cumulative leachate volume from the 5-foot collector at a C-a is shown in Figure 5 along with the C-a precipitation. Again, there is a correspondence between the two curves, and the volume collected is 16 percent of the precipitation total. Volumes of leachate from the 10-foot and 15-foot collectors at C-a are 6.67 cm and 6.26 cm, respectively. It is speculated that settlement subsequent to construction caused the collectors at C-a to become tilted, and hence, less effective. Even though similar settlement may have occurred at C-b, the substantially higher rise of the edges provided on the C-b collectors is thought to have prevented settlement from reducing the effectiveness of the collectors. With the exception of the 10-foot collectors at C-a, all collectors have been effective in producing samples for chemical analysis. Presumably, the inefficiency of the collectors affects only the volume and not the quality of the leachate.

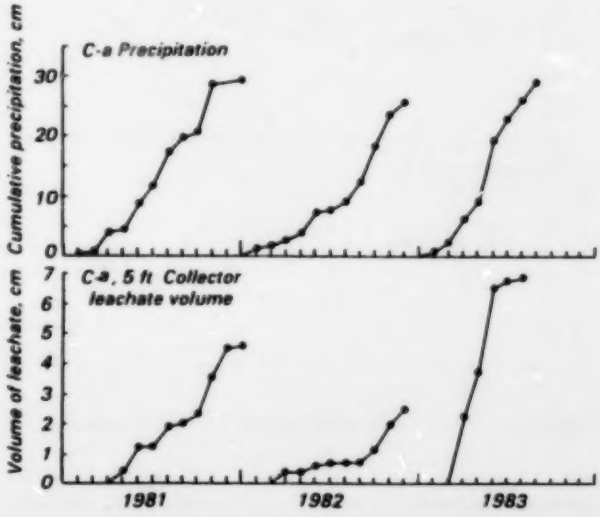

Figure 5. Volumes of leachate and precipitation at C-a.

Electrical Conductivity and pH

Electrical conductivity (EC) and pH were measured in the field at the time each sample was collected. Figure 6 shows the EC and pH of leachate produced from the two reliable collectors at C-a. The pH of leachate from the two collectors ranges from 6.9 to 7.9. There is no apparent pattern or trend in the pH data. The mean EC values are approximately 30,600 μmhos/cm and 18,300 μmhos/cm for the 15-foot and 5-foot collectors, respectively. Among the possible explanations for the difference between the two mean values is the possibility that the materials overlying the collectors is not the same. Different residence times and variations in the partial pressures of carbon dioxide and oxygen with depth may also contribute. No trend toward lower EC is discernible in these data and is not yet expected in view of the relatively small quantities of throughput that have occurred to date.

Corresponding data for the C-b collection system are shown in Figure 7. Data for the 20-foot collector are very nearly the same as that shown and were omitted in the interest of clarity. The small differences in pH and EC measured at the three depths are not believed to be statistically significant and should not be interpreted as indicating a trend. Comparison with the data from C-a points up three significant contrasts between the two sites. First, the mean pH of the C-b leachates is slightly greater than of the C-a leachates. More significant, however, is the observation that the EC values tabulated average 6950 μmhos/cm, less than one-fourth of the mean EC for the 15-foot collector at C-a. The chemical composition of the leachates at the two sites are also greatly different as discussed in a subsequent

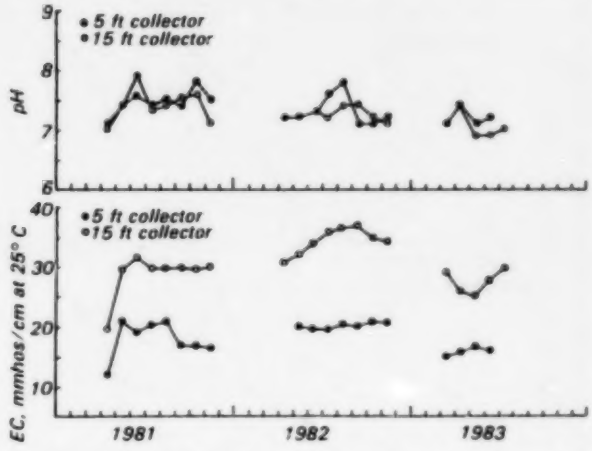

Figure 6. Electrical conductivity and pH for C-a collectors.

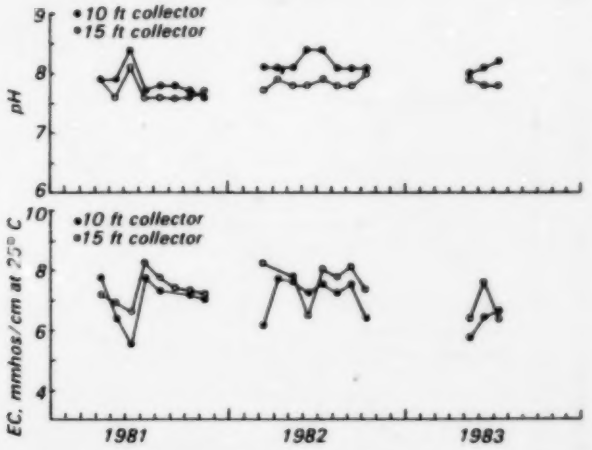

Figure 7. Electrical conductivity and pH for C-b collectors.

section. The third contrast with the C-a data is that the EC of leachate at C-b did not increase with depth. This observation casts doubt on different residence times as a viable explanation of the observed differences in EC for the 5-foot and 15-foot collectors at C-a. As was the case for C-a, the data in Figure 7 do not exhibit a trend toward lower EC with increasing time.

Quality of Leachate

Many of the samples collected from bottles A, B, and C were prepared for chemical analysis. Analyses of waters contained in bottles B and C did not often differ significantly from those of bottle A water. Presentation and discussion of data from bottle A only is contained in this report. The chemical analyses reported herein represent approximately 70 percent of the total number of such analyses performed on leachate samples. The remaining analyses were from bottles B and C and occasional duplicate runs.

The major ion chemistry of leachate from the C-a collectors is presented in Tables 2 and 3. The waters are saline with total dissolved solids concentrations ranging upwards of 70,000 mg/l. Dissolved constituents are dominated by magnesium and sulfate. The concentration of calcium in leachate from both collectors suggests that the calcium concentration is controlled by the solubility of calcium sulfate. The magnesium concentration does not appear to be solubility controlled.

Tables 4 and 5 contain data on the major ion composition of leachates collected at C-b. In contrast with C-a, the concentration of dissolved solids in C-b leachate is much lower. Also, the composition of the C-b leachates is dominated by sodium and sulfate rather than magnesium and sulfate. As in the C-a leachates, it appears that the calcium concentration is controlled by the solubility of calcium sulfate. A complete explanation for the marked differences between the leachates at C-a and C-b remains unknown. However, it is known that the C-b shale came from an interval of lean shale with a greater *in-situ* permeability than at C-a. This lean shale is expected to be of a different composition than the rich layer mined at C-a. The larger permeability of the lean shale could also have resulted in more effective pre-leaching by groundwater prior to mining.

The concentration of nitrates in the leachate from both C-a and C-b is greater than was anticipated. One obvious source for nitrates is residual from the explosives used in mining the shale. If this is indeed the major source, it is expected that a trend toward lower nitrate concentrations should be observed as a result of washing the residual explosive from the particle surfaces. Throughput volumes to date are too small to expect observation of a decreasing trend at this time.

Tables 6 and 7 present a summary of selected trace element concentrations observed in the leachate from C-a. Similar data for C-b are contained in Tables 8 and 9. Analyses for several other trace elements were performed, but those shown in Tables 6 through 9 are most significant. Fluoride concentrations in leachate from the C-a collectors ranged between 8.5 and 36.1 mg/l. Concentration of F observed in the C-a, 15-foot collector was significantly greater than in the 5-foot collector leachate. Fluoride concentrations in C-b leachate ranged from 4.2 to 10.5 mg/l and the data do not show any trend with depth of collector. The concentrations of fluoride observed in the field-generated leachates are similar to those measured in a previous column leaching study, although the raw shales in the columns were not duplicates of those that overlay the collectors.

Concentrations of zinc and boron are similar in the C-a and C-b leachates, but both are significantly less than the maximum values observed for these elements in the previous column leaching tests. Again, the difference results from differences in materials used in the two studies. Mo concentrations are generally similar at the two sites. The Mo data at C-b show a significant decreasing trend with time in 1981, but recovered in 1982. Concentrations of the other elements in these tables are similar for both sites and with respect to depth. No reliable time trends toward lower concentrations are discernible in the trace element data. Again, it is emphasized that only a small

Table 2. *Major Ion Composition of C-a Leachate—1981*

Date	Ca	Mg	Na	K	SO_4	Cl	HCO_3	NO_3	TDS	Balance*
				meq/l					mg/l	%
					C-a, 5 Foot Collector					
4/03	22.0	86.4	16.3	0.2	98.3	2.1	3.2	10.4	8720	+ 3.6
5/07	35.9	401.3	43.3	0.3	568.0	4.9	6.6	34.2	32960	-12.1
7/15	37.3	415.3	40.7	0.2	416.4	4.5	6.0	33.3	32630	+ 3.6
8/11	23.9	368.8	40.2	0.2	445.6	5.4	5.7	27.1	30950	- 5.7
9/14	30.9	293.6	30.4	0.2	310.2	3.0	6.3	25.8	24230	+ 1.5
10/09	31.9	340.5	32.3	0.2	385.2	3.5	6.5	24.0	26850	+ 4.7
11/19	29.9	396.4	42.2	0.2	483.2	6.2	6.6	27.2	32860	- 5.8
Mean**	31.6	369.3	38.2	0.2	427.1	4.6	6.3	28.6	30080	
					C-a, 15 Foot Collector					
4/03	29.5	327.3	42.4	0.3	486.4	8.5	2.6	26.2	26210	-13.4
5/07	28.2	600.3	56.6	0.3	768.7	11.3	3.7	31.0	47040	- 8.6
7/13	25.6	662.0	51.3	0.2	624.6	9.3	6.6	31.6	49700	+ 4.8
8/24	32.4	695.7	55.2	0.2	764.1	10.6	5.7	30.5	54820	- 1.8
9/10	26.5	703.5	53.1	0.3	770.4	8.4	6.2	24.0	54530	- 1.7
10/05	26.5	713.0	53.5	0.2	680.8	11.6	5.4	30.2	54520	+ 4.3
11/19	28.9	749.2	58.7	0.2	822.4	10.6	4.1	33.9	59477	- 2.0
Mean**	28.0	637.3	54.7	0.2	738.5	10.3	5.3	30.2	53350	

* Balance = (meq Cations - meq Anions)/Total meq
**Exclusive of sample on 4-3

Table 3. *Major Ion Composition of C-a Leachate—1982, 1983*

Date	Ca	Mg	Na	K	SO_4	Cl	HCO_3	NO_3	TDS	Balance*
				meq/l					mg/l	%
					C-a, 5 Foot Collector					
3/16/82	20.1	196.3	22.1	0.3	25.0	2.1	4.6	11.6	17480	- 5.4
5/27	20.0	360.1	37.8	0.2	482.5	5.3	6.1	22.6	29810	-10.5
6/07	18.9	339.9	26.3	0.2	383.1	5.1	3.2	22.1	29550	- 3.5
7/01	18.8	373.7	21.4	0.3	414.3	5.9	5.4	22.6	28900	- 3.9
8/04	22.7	397.4	32.4	0.2	424.7	5.0	5.6	17.3	26440	0.0
9/21	20.2	341.6	34.7	0.2	453.9	3.9	5.5	21.4	29520	-10.0
Mean**	20.1	362.5	30.5	0.2	431.7	5.0	5.2	21.2	28840	
6/21/83	12.2	253.5	24.1	0.1	311.9	4.6	4.0	16.3	24500	- 7.0
					C-a, 15 Foot Collector					
3/16/82	24.0	665.4	61.3	0.3	796.8	7.3	3.8	27.2	57350	- 5.3
4/12	23.5	786.8	53.7	0.2	743.3	8.2	4.5	32.1	62190	+ 4.6
5/17	22.0	812.8	57.0	0.2	946.7	8.5	4.9	37.6	65670	- 5.6
6/02	19.4	733.3	55.2	0.2	784.9	9.3	6.2	36.6	64900	- 1.8
7/01	20.2	765.4	57.4	0.2	816.2	10.3	6.7	39.0	66570	- 1.7
8/04	16.3	1002	70.0	0.4	862.0	10.9	7.8	33.9	71320	+ 8.7
9/21	17.8	1128	64.8	0.4	891.1	8.9	9.5	35.3	71960	+12.3
Mean**	19.9	871.4	59.7	0.3	840.7	9.4	6.6	35.8	67100	
6/21/83	12.2	--	52.9	0.1	801.8	8.6	5.1	25.3	54200	--

* Balance = (meq Cations - meq Anions)/Total meq
**Exclusive of sample 3/16

Table 4. Major Ion Composition of C-b Leachate—1981

Date	Ca	Mg	Na	K	SO_4	Cl	HCO_3	NO_3	TDS	Balance
				meq/l					mg/l	%
					C-b, 10 Foot Collector					
4/08	12.2	12.8	48.3	0.2	69.2	0.4	3.3	4.9	5950	-1.8
4/21	17.8	10.9	42.1	0.2	65.6	0.4	2.9	3.5	5140	- 0.2
5/12	18.1	14.2	45.2	0.2	63.5	0.5	2.6	3.9	5690	+ 5.6
6/19	26.8	15.2	45.7	0.1	65.8	0.3	2.9	2.2	6120	-11.0
7/23	30.4	18.6	45.7	0.1	83.7	0.3	3.0	1.8	6930	+ 3.6
8/21	22.5	19.7	46.5	0.2	86.4	0.3	3.0	1.6	7120	- 0.8
9/10	24.5	21.2	45.7	0.2	85.4	0.3	3.1	1.3	7260	+ 1.2
10/09	31.4	23.2	44.4	0.1	82.0	0.3	3.2	1.3	7230	+ 7.1
11/23	18.5	24.9	45.2	0.2	88.7	0.5	2.5	2.2	6590	- 2.2
Mean	22.5	17.9	45.4	0.2	76.7	0.4	2.9	2.5	6450	
					C-b, 15 Foot Collector					
4/08	17.5	12.8	49.2	0.1	74.4	0.4	3.4	2.6	6030	- 0.5
5/12	19.0	16.2	46.5	0	75.8	0.4	2.7	2.8	6200	+ 0.4
6/19	21.7	18.7	48.7	0.1	71.6	0.4	2.8	1.9	6830	+ 8.3
7/08	26.0	20.1	47.4	0.1	87.9	0.3	2.5	1.7	7260	+ 1.1
8/21	26.5	22.4	48.3	0.2	93.3	0.3	2.7	1.4	7650	+ 0.2
9/10	27.0	23.8	47.8	0.2	94.5	0.3	3.1	1.1	7740	+ 0.3
10/09	24.4	25.2	45.2	0.1	80.8	0.5	3.3	0.9	7560	+ 5.8
11/23	21.0	28.0	47.4	0.2	89.8	0.5	2.4	2.0	7120	+ 1.4
Mean	22.9	20.9	47.6	0.1	83.5	0.3	2.9	1.8	7050	
					C-b, 20 Foot Collector					
4/21	20.5	15.2	40.6	0.2	65.5	0.5	2.3	2.9	5580	+ 2.8
5/12	17.9	15.1	38.5	0.1	68.6	0.7	2.4	3.3	5590	- 1.8
6/19	28.4	17.9	44.4	0.2	68.4	0.7	2.4	2.7	6360	+10.7
7/23	26.4	20.5	44.4	0.1	83.5	0.7	2.3	2.5	6980	+ 1.6
8/21	26.0	21.8	45.7	0.1	83.5	0.7	2.4	2.1	7160	+ 2.9
9/10	18.5	22.9	45.2	0.1	80.8	0.7	2.5	2.1	7310	+ 0.6
11/23	22.0	20.7	45.7	0.3	86.2	0.6	2.0	3.3	6580	- 1.5
Mean	22.8	19.2	43.5	0.1	76.6	0.7	2.3	2.7	6510	

volume of leachate has been collected relative to the pore volume of the shale overlying each collector. In an attempt to provide a more meaningful overview of the entire data set on leachate quality, the data were searched for the maximum value of each species. The results are shown in Table 10. In preparation of this table, a few obvious outliers were ignored. The maximum value of 113 mg/l for fluoride may be an outlier, but this could not be determined with confidence. Given the large number of measurements made over the nearly three years of study, the probability that the tabulated value of any particular species is exceeded a significant fraction of the time is considered to be very small. Thus, Table 10 presents a reasonable worst-case picture for the shales studied.

Laboratory Leaching Tests

The ASTM water shake extraction tests for the materials overlying the collectors were performed and are compared with field data in this section. Table 11 contains the chemical analysis for the filtrate from the water shake extraction test.

The large water-to-shale ratio and the vigorous agitation used in the water shake tests makes it reasonable to expect that the dissolved solids concentration in the filtrate is indicative of the total soluble salt content of the shales. A dry weight of 700 g of each shale was agitated in 2.8 liters of distilled water. The concentrations of total dissolved solids given in Table 11 are readily converted to soluble salt contents on a weight basis. The soluble salt content of the C-a raw shale is 9.7 g/kg and of the C-b shale is 2.8 g/kg. The effect of water-to-shale ratio on this determination was investigated by repeating the test on the C-a shale, using 165 g of dry shale in 3.3 liters of water (i.e., a 20:1 ratio instead of a 4:1). The soluble salt content for this test was 13.5 g/kg, some 39 percent greater than determined with the smaller water-to-shale ratio. Two other materials (USBM raw shale and TOSCO II retorted shale) were similarly tested with similar results. The 20:1 water-to-

Table 5. Major Ion Composition of C-b Leachate—1982, 1983

Date	Ca	Mg	Na	K	SO_4	Cl	HCO_3	NO_3	TDS	Balance*
				meq/l					mg/l	%
					C-b, 10 Foot Collector					
4/05/82	20.1	24.6	40.0	0.1	78.5	0.3	2.3	1.2	6080	+ 1.5
5/18	20.0	27.7	43.5	0.1	102.9	0.4	2.9	1.2	7160	- 8.1
6/21	22.3	28.5	50.5	0.2	77.2	0.4	3.1	0.7	7200	+11.0
7/12	22.9	29.2	60.9	0.1	89.9	0.3	3.0	0.5	7430	+ 9.4
8/04	21.4	30.3	45.2	0.2	81.6	0.4	3.5	0.2	7300	+ 6.2
9/03	23.0	28.7	46.5	0.2	82.0	0.4	2.8	0.6	7300	+ 6.8
Mean	21.6	28.2	47.8	0.2	85.4	0.4	2.9	0.7	7080	
					C-b, 15 Foot Collector					
4/05	11.6	32.7	53.3	0.1	87.6	0.4	2.2	1.3	7180	- 3.3
5/18	21.0	33.2	48.7	0.2	104.1	0.5	2.6	1.2	7890	- 2.5
6/21	14.1	30.2	49.1	0.2	90.8	0.5	2.6	0.8	7670	- 0.6
7/12	22.8	31.1	66.1	0.2	90.6	0.5	2.7	0.6	7620	+12.0
8/04	22.7	35.7	46.1	0.1	108.7	0.5	2.8	0.5	7640	- 3.6
9/16	21.4	38.3	47.8	0.1	87.9	0.4	2.7	2.0	7570	+ 7.3
Mean	18.9	33.5	51.8	0.2	94.9	0.5	2.6	1.1	7600	
6/21/83	21.8	32.0	29.5	0.1	114.5	0.9	2.4	3.6	6890	-18.6
					C-b, 20 Foot Collector					
4/05/82	20.1	22.9	35.2	0.1	77.4	0.4	2.0	1.1	5940	- 1.6
5/27	18.5	17.3	37.4	0.1	82.0	0.6	2.2	2.7	5900	- 8.8
6/21	22.9	24.6	56.1	0.2	84.1	0.5	2.1	0.2	6720	+ 8.9
7/12	23.5	25.3	48.7	0.2	86.8	0.5	2.3	1.7	7060	+ 3.4
8/04	23.9	28.8	46.5	0.1	79.5	0.7	2.4	1.4	6980	+ 8.3
9/16	20.6	19.3	47.0	0.1	71.8	0.4	2.1	4.3	6240	+ 5.2
Mean	21.6	23.0	45.1	0.1	80.3	0.5	2.2	1.9	6470	
6/21/83	25.2	31.0	48.9	0.2	104.5	0.5	2.1	1.0	7910	- 1.3

*Balance = (meq Cation - meq Anions)/Total meq

shale ratio yielded soluble salt contents 38 and 29 percent greater than did the 4:1 ratio for USBM raw shale and TOSCO II retorted shale, respectively.

This study investigated the degree to which the TDS concentration in the shake test filtrate can be used to predict the TDS concentration in field-generated leachate. The simplest method for accomplishing this is the highly questionable premise that the total weight of dissolved solids is independent of the volume of water in which they are dissolved. Data in the above paragraph and other chemical principles suggest that this is a false premise. Nevertheless, if such a calculation would provide even roughly correct estimates of TDS, it would be useful. The in-place dry bulk density of the shales overlying the collectors is estimated at 1.4 g/cm^3. The porosity is also estimated to be 0.45. When the pores are saturated, the corresponding water-to-shale ratio is 0.32. Thus, the TDS concentration in the filtrate from the 4:1 water-to-shale shake test can be converted to the corresponding value with a 0.32:1 ratio by multiplying by 4/0.32 = 12.5. On this basis, the 2427 mg/l value for the C-a raw shale converts to 30,200 mg/l. This is surprisingly close agreement with the 1981 field measured value of 30,080 mg/l at the 5-foot depth (see Table 2). A similar calculation for the C-b raw shale yields 8875 mg/l as compared to an average of 6450 mg/l measured from the 10-foot collector in 1981. Again, this is a reasonable agreement considering that the bulk density and porosity of the raw shale piles in the field are only estimated values.

The above indicated agreement between measured and calculated values of TDS concentration is believed to be largely fortuitous, however. The chemical composition of the filtrate from the shake tests bears little resemblance to that of the field-generated leachates as shown in Table 12. The disparity in the compositions of the filtrates and the field leachates is not surprising. The concentrations of one or more of the constituents in the field leachate may be solubility controlled. The much greater water-to-shale ratio in the shake tests is expected to remove this constraint on concentration. For example, the 3.5 percent Ca in C-a

Table 6. Selected Trace Elements in C-a Leachate—1981

Date	F	Zn	B	Si	Mo	Mn	Ni	Al	Sr
				Mg/l					
				C-a, 5 Foot Collector					
4/03	8.5	0.218	0.216	4.6	<0.05	0.439	0.18	1.1	4.2
5/07	12.5	0.401	0.445	2.9	<0.05	3.060	0.67	0.7	7.9
7/15	11.9	0.270	0.510	3.3	<0.05	2.500	0.61	<0.02	7.3
8/11	--	0.154	0.480	3.1	<0.05	2.070	0.29	0.1	6.5
9/14	9.0	0.202	0.550	4.4	<0.05	2.300	0.31	<0.02	5.0
10/09	9.2	0.176	0.520	4.2	<0.05	1.950	0.25	<0.02	5.2
11/19	11.3	0.203	0.472	3.6	0.22	0.710	0.23	0.31	6.8
				C-a, 15 Foot Collector					
4/03	17.8	0.118	0.377	2.3	<0.05	0.793	0.29	0.7	6.8
5/07	22.0	0.175	0.480	2.2	<0.05	2.230	0.51	0.6	10.9
7/13	20.2	0.281	0.500	2.8	<0.05	2.500	0.63	<0.02	10.2
8/24	--	0.183	0.380	1.1	<0.05	2.000	0.26	<0.02	8.5
9/10	--	0.201	0.480	1.9	<0.05	1.970	0.28	<0.02	8.0
10/05	19.0	0.186	0.510	2.9	<0.05	2.200	0.18	<0.02	6.6
11/19	23.0	0.129	0.495	2.8	0.21	1.000	0.10	0.10	7.8

Table 7. Selected Trace Elements in C-a Leachate—1982

Date	F	Zn	B	Si	Mo	Mn	Ni	Al	Sr
				Mg/l					
				C-a, 5 Foot Collector					
3/16	14.2	0.012	0.071	2.4	<0.05	0.016	0.017	<0.02	2.0
6/07	16.7	0.182	0.658	6.4	1.12	1.83	0.66	4.15	7.8
7/01	19.4	0.158	0.719	5.7	1.11	1.29	0.63	5.28	8.3
8/30	20.3	0.113	--	5.1	0.38	0.14	0.20	<0.50	7.7
9/21	36.1	0.211	--	2.6	<0.03	0.37	0.20	<0.50	6.8
				C-a, 15 Foot Collector					
3/16	30.4	0.111	0.296	7.0	<0.05	1.01	0.13	1.72	9.7
4/12	24.3	0.128	0.430	6.0	<0.05	0.05	0.05	<0.02	2.9
6/02	22.4	0.188	1.54	13.2	0.61	2.34	1.12	4.37	8.3
7/01	32.6	0.243	1.28	<0.5	0.66	1.84	1.08	1.68	9.3
7/19	28.6	0.255	1.05	<0.5	0.36	1.46	0.66	1.26	15.4
8/04	30.0	0.393	1.39	5.8	0.50	2.21	0.20	1.70	13.4
9/21	42.2	0.311	--	1.3	<0.03	0.37	0.75	<0.5	11.0

leachate represents 31.6 meq/l which is approximately the saturated value for a calcium sulfate solution. The much greater 23.2 percent Ca in the shaker filtrate represents only 17.5 meq/l, well below the concentration for a saturated calcium sulfate solution. Apparently, the concentration of calcium in the field leachate is limited by the solubility of calcium sulfate, but is not so limited in the shake test.

Similar considerations are expected to apply for the trace elements. Table 13 compares the concentrations of selected trace species in the shaker filtrate with field values. The shake values have been multiplied by 12.5 to convert them to approximately the water-to-shale ratio believed to represent field conditions. Again, there is little or no quantitative correspondence between the measured and calculated concentrations.

Conclusions

The results of the investigation of the quantity and quality of leachate from raw shale piles warrant the following conclusions. It is emphasized that the results and conclusions reported herein are specific to the shales studied.

Table 8. *Selected Trace Elements in C-b Leachate—1981*

Date	F	Zn	B	Si	Mo	Mn	Ni	Al	Sr
					Mg/l				
				C-b, 10 Foot Collector					
4/08	8.7	0.052	0.626	4.9	11.3	0.140	0.33	2.5	11.3
4/21	6.9	0.155	0.494	4.2	6.9	0.117	0.23	1.6	8.6
5/12	6.4	0.455	0.269	3.2	5.2	0.100	0.31	2.8	12.0
6/19	6.4	0.154	0.394	4.5	2.5	0.150	0.31	2.5	11.0
8/21	10.5	0.173	0.650	5.9	1.6	0.200	0.13	<0.02	7.2
9/10	10.4	0.188	0.650	5.7	1.2	0.180	0.14	<0.02	6.9
10/09	6.1	0.194	0.690	5.9	0.49	0.150	0.10	<0.02	6.9
11/23	6.6	0.127	0.478	3.7	2.21	0.081	0.071	1.21	8.1
				C-b, 15 Foot Collector					
4/08	9.6	0.189	0.456	4.0	6.9	0.133	<0.05	1.1	6.9
5/12	6.5	0.155	0.299	3.0	3.4	0.103	<0.05	1.9	8.7
6/19	6.9	0.306	0.486	4.8	3.3	0.180	0.36	3.0	15.0
7/08	10.5	0.239	0.550	4.6	1.8	0.230	0.18	<0.02	10.0
8/21	10.3	0.280	0.580	4.8	1.0	0.210	0.19	<0.02	9.2
9/10	10.2	0.319	0.600	5.1	0.6	0.180	0.19	<0.02	7.7
10/09	6.4	0.373	0.590	5.0	0.7	0.140	0.16	<0.02	7.0
11/23	6.4	0.172	0.479	3.6	1.9	0.077	0.08	0.88	7.1
				C-b, 20 Foot Collector					
4/21	5.9	0.095	0.434	3.8	3.6	0.120	0.25	0.8	11.0
5/12	5.8	0.367	0.288	2.7	3.2	0.078	0.50	1.2	9.6
6/19	6.2	0.166	0.410	4.7	2.5	0.160	0.33	1.2	14.0
7/23	9.9	0.184	0.420	3.2	0.9	0.160	0.16	<0.02	8.8
8/21	9.8	0.203	0.440	3.5	0.6	0.160	0.16	<0.02	8.4
9/10	9.6	0.206	0.440	3.5	<0.05	0.140	0.15	<0.02	9.1
10/09	5.1	0.050	0.240	3.9	<0.05	0.058	0.06	<0.02	3.6
11/23	5.6	0.076	0.372	3.4	1.61	0.035	0.07	0.70	8.6

Extrapolation of the results or conclusions to other conditions is not recommended.

1. The cumulative volume of leachate per unit measured over nearly three years at federal lease tract C-a ranged from 6.26 to 13.72 cm. These volumes represent 7 and 16 percent, respectively, of the incident precipitation over the same time period. The larger value is believed to be more representative of the actual volume of leachate generated in the pile.
2. The cumulative volume of leachate per unit area measured over nearly three years at federal lease tract C-b ranged from 11.52 to 17.02 cm. These volumes represent 12 and 17 percent, respectively, of the incident precipitation over the same time period.
3. Leachate volumes of the above magnitudes are believed to be larger than the natural recharge rates on undisturbed lands receiving similar volumes of precipitation. The raw shale piles were formed from mine-run size material and remained unvegetated. Therefore, infiltration capacity was high and both evapotranspiration and direct runoff capacity were low.
4. Leachate from the raw shale at C-a was highly saline. The mean concentration of dissolved solids in the 5-foot collector was 29,500 mg/l. At the 15-foot depth, the mean concentration of dissolved solids was 60,220 mg/l. These waters were found to be a magnesium-sulfate type, with these two constituents accounting for 87 percent of the total equivalent weight of dissolved species. The pH ranged from 6.9 to 7.9 throughout the study.
5. Leachate from the raw shale at C-b contained a much smaller quantity of dissolved solids than did the C-a leachate. The C-b leachate is a sodium-sulfate solution with an average concentration of dissolved solids of 6850 mg/l. The pH ranged from 7.4 to 8.4.
6. Trace element concentrations in leachate from both sites were generally low in view of the large concentrations of the common ionic species. Although the concentrations of many trace elements were sometimes observed to be greater than the various recommended maxima for particular uses, the large concentration of common species is more likely to be the significant quality characteristic of these waters.

Table 9. Selected Trace Elements in C-b Leachate—1982

Date	F	Zn	B	Si	Mo	Mn	Ni	Al	Sr
				Mg/l					
				C-b, 10 Foot Collector					
4/05	4.23	0.021	0.370	6.7	<0.05	0.06	0.006	<0.02	4.4
6/21	5.55	<0.001	0.94	11.4	1.4	0.47	0.047	1.72	7.2
7/06	5.80	0.004	0.64	7.0	1.4	0.45	0.034	1.57	7.5
7/12	5.81	0.296	0.89	7.6	0.36	0.08	0.034	0.91	6.4
8/04	4.72	0.041	0.99	9.2	1.5	0.06	0.047	1.37	8.1
9/08	6.88	0.003	--	3.9	0.9	<0.005	<0.05	--	5.6
				C-b, 15 Foot Collector					
4/05	6.98	0.158	0.51	3.4	<0.05	0.07	0.063	<0.02	3.7
6/21	6.44	0.188	0.82	4.6	1.2	<0.02	0.073	2.07	7.2
7/06	--	0.188	0.91	3.0	1.4	0.22	0.060	1.42	9.0
7/12	6.35	0.118	0.64	5.4	0.28	0.10	0.060	1.58	7.9
8/04	7.39	0.371	0.91	5.4	1.3	0.08	0.086	1.16	7.9
9/16	6.88	0.113	--	1.7	1.1	<0.005	<0.05	--	6.1
				C-b, 20 Foot Collector					
4/05	4.65	0.076	0.36	2.4	<0.05	0.045	0.046	<0.02	7.5
6/21	4.73	0.104	0.75	3.6	0.80	0.47	0.047	1.05	8.9
7/06	5.00	0.110	0.81	1.2	1.5	0.52	0.047	1.89	8.9
7/12	4.90	0.116	0.64	3.1	1.1	0.054	0.073	0.94	8.4
8/04	6.82	0.164	0.92	6.8	1.1	0.146	0.060	2.25	6.5
9/16	4.58	0.084	--	1.7	1.1	<0.005	<0.05	--	5.7

7. No trends toward improvement in quality with time were observed. The volumes of leachate generated in the study period are small relative to the pore volume of the shales overlying the collectors. Improvement in quality is not likely until the volume of leachate exceeds at least 0.5 pore volumes.

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Table 10. Maximum Observed Concentrations

Species	Concentration mg/l	Location	Date
HCO_3	579	C-a, 15 Ft	9/21/82
CO_3	5.68	C-a, 15 Ft	7/19/82
TDS	72660	C-a, 15 Ft	8/16/82
F	113	C-a, 15 Ft	7/26/82
Cl	366	C-a, 15 Ft	7/01/82
PO_4	0.28	C-b, 20 Ft	2/25/82
NO_3	2564	C-a, 15 Ft	7/26/82
SO_4	45900	C-a, 15 Ft	5/10/82
Zn	0.597	C-a, 15 Ft	8/16/82
Fe	2.02	C-a, 15 Ft	8/11/82
Co	1.17	C-a, 15 Ft	8/23/82
Li	0.339	C-b, 10 Ft	7/26/82
NH_3	2.55	C-a, 5 Ft	8/30/82
B	1.97	C-b, 15 Ft	7/26/82
Cd	0.168	C-a, 15 ft	7/26/82
Be	0.300	C-b, 10 Ft	7/06/82
Mg	12830	C-a, 15 Ft	9/06/82
P	7.0	C-a, 15 Ft	8/04/82
Si	13.2	C-a, 15 Ft	6/02/82
Mo	1.5	C-b, 10 Ft	7/06/82
Mn	2.34	C-a, 15 Ft	6/02/82
Ni	1.12	C-a, 15 Ft	6/02/82
Na	2030	C-a, 15 Ft	8/02/82
Cu	0.073	C-b, 10 Ft	7/06/82
Al	5.28	C-a, 5 Ft	7/01/82
Ca	505	C-a, 15 Ft	3/22/82
Ba	0.822	C-b, 10 Ft	9/23/82
K	16.4	C-a, 15 Ft	7/19/82
Cr	0.290	C-a, 15 Ft	6/02/82
Sr	15.4	C-a, 15 Ft	7/19/82
Pb	1.036	C-a, 15 Ft	8/11/82
Ag	0.012	C-a, 15 Ft	3/17/82
Tl	0.007	C-a, 15 Ft	4/12/82
Se	0.013	C-a, 15 Ft	7/01/82
As	0.007	C-b, 20 Ft	8/04/82
Hg	0.003	C-b, 20 Ft	2/25/82

Table 11. Chemical Analysis of Water Shake Extraction Test

Parameter		C-a* Raw	C-b** Raw
pH	--	8.22	8.57
EC	µmhos/cm	2500	850
ALK	mg/l	124.4	119.2
H_2CO_3	mg/l	2.00	0.85
HCO_3	mg/l	149.6	140.9
CO_3	mg/l	1.06	2.24
TDS	mg/l	2427	710
F	mg/l	1.52	2.39
Cl	mg/l	84.5	2.75
PO_4	mg/l	0.8	<0.03
NO_3	mg/l	112	11.9
SO_4	mg/l	1480	315
Zn	mg/l	0.015	0.008
Fe	mg/l	0.011	<0.005
Co	mg/l	<0.005	<0.005
Li	mg/l	0.098	0.083
V	mg/l	<0.001	<0.001
NH_3	mg/l	0.158	0.292
B	mg/l	0.166	0.120
Cd	mg/l	<0.001	<0.001
Be	mg/l	<0.0005	0.0009
Mg	mg/l	173	38
P	mg/l	0.05	<0.05
Si	mg/l	3.0	1.9
Mo	mg/l	0.3	0.58
Mn	mg/l	0.053	0.010
Ni	mg/l	0.007	0.006
Na	mg/l	117	76
Cu	mg/l	0.005	0.003
Al	mg/l	0.20	0.23
Ca	mg/l	350	50
Ba	mg/l	0.076	0.142
K	mg/l	7.0	14
Cr	mg/l	0.01	0.007
Sr	mg/l	5.1	1.9
Pb	mg/l	0.008	0.011
Ag	mg/l	<0.001	<0.001
Tl	mg/l	<0.005	<0.005
Se	mg/l	<0.020	<0.020
As	mg/l	<0.010	<0.010
Hg	mg/l	0.001	<0.001
Total N	mg/l	0.18	1.94

* Raw shale overlying 5-foot collector at C-a.

**Raw shale overlying 10-foot collector at C-b.

Table 12. *Comparison of Composition of Shake Test Filtrates with 1981 Field Leachates*

	Percent of Total Milliequivalents			
	C-a Raw Shale		C-b Raw Shale	
Constituent	Shake	Field	Shake	Field
Ca	23.2	3.5	13.1	13.3
Mg	18.9	40.8	16.4	10.6
Na	6.8	4.2	17.4	26.9
K	0.2	~0	1.9	0.1
SO_4	41.0	47.2	34.4	45.5
HCO_3	3.3	0.4	12.1	1.7
Cl	3.2	0.4	0.4	0.2
NO_3	2.4	3.2	1.0	1.5

Table 13. *Trace Element Concentrations in Shake Filtrate Compared with 1981 Field Leachate Values*

	Concentration, mg/l			
	C-a		C-b	
Element	Shake*	Field	Shake*	Field
F	19.0	10.4	29.9	7.8
Zn	0.188	0.232	0.100	0.187
B	2.075	0.456	1.50	0.531
Si	37.5	3.7	23.8	4.6
Mo	3.75	<0.05	7.2	3.9
Mn	0.662	2.290	0.13	0.14
Ni	0.088	0.363	0.08	0.20
Al	2.5	<0.3	2.9	<1.3
Sr	63.8	6.1	23.8	9.0

**The shake values have been multiplied by 12.5 to convert them to approximately the water-to-shale ratio believed to represent field conditions.*